HOW DO YOU GO FROM A CONCEPT IDEA TO A NASA SELECTED MISSION? FORMULATING THE PSYCHE DISCOVERY MISSION WITH JPL'S CONCURRENT ENGINEERING TEAMS

Kelley Case [(1)], Linda T. Elkins-Tanton [(2)], Alfred Nash [(1)], David Oh [(1)], and John Ziemer [(1)]

[(1)] Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA
[(2)] Arizona State University, PO Box 876004, Tempe, AZ 85287-6004 USA

ABSTRACT

JPL's Office of Formulation provides continuity of support and access to domain subject matter experts, as Principal Investigators mature their mission concepts from "cocktail napkin" ideas to Preliminary Design Reviews [1]. Using NASA's Psyche mission as a case study, we describe JPL's concurrent engineering A-Team and Team X support to the Psyche competed concept study team in the areas of 1) Initial Feasibility, 2) Trade Space Exploration, 3) Spacecraft Point Design and Cost Estimate, 4) Science, Technical, Management, and Cost Review, and 5) Strategy and Communication Development.

NASA's Psyche Discovery-class mission started as a grassroots idea from Principal Investigator L.T. Elkins-Tanton. ***Is there a compelling Discovery mission to visit the interior of a body for the first time, by sending a mission to an iron metal asteroid?*** In less than five years the Psyche concept was selected as a mission under NASA's Discovery Program. While Psyche had a dedicated concept development team [2], they utilized JPL's concurrent engineering teams, methods, analysis tools, and subject matter experts throughout their mission concept formulation lifecycle.

1. INITIAL FEASIBILITY

Prior to investing time and resources into a concept idea, it is critical to consider the science feasibility, which has two aspects: science merit and science implementation. Science merit is determined by the compelling nature of the investigation and the prioritization defined by Decadal Survey science committees. ***Is the science worth doing?*** Science implementation is determined by the likelihood to succeed and the probability of technical success based on the scientific and technical approach. ***Will the science objectives be achieved?***

The first step on Psyche's road to success was an A-Team study focused on science feasibility. A-Team was conceived to assess technical, cost, and science feasibility, and to construct and conduct mission architecture-level trades. The study was conducted in a workshop style format with participation from scientists and engineers, but leveraging concurrent engineering methods, experts, and analysis tools. The purpose of the study was to assess whether to proceed with the idea of exploring one or more metal asteroids (Fig. 1) as a compelling Discovery class mission concept.

Image Credit: ASU/Peter Rubin

Figure 1. The largest metal asteroid, Psyche preserves a key step in the formation of terrestrial planets including Earth. The first mission to a metal world will map features, structure, composition, and magnetic field [3].

A-Team study objectives were to refine the science questions, then generate several potential "architecture seeds" that would address those science questions, and identify the driving factors between the architecture seeds. Science questions drive our early concept formulation and its impact to the mission and flight system requirements. Furthermore, it is critical for the science team to understand the gradient in science return for various mission scenarios and payload options.

The Psyche mission concept was crafted to be highly relevant and responsive to the National Research Council (NRC) Decadal Survey, Vision and Voyages [4]. Psyche's science team ultimately chose the following five science questions, which are directly traceable to their definitive science objectives:

A. Is Psyche a core, or did it never undergo melting?
B. What are the relative ages of its surface regions?
C. Do small metal bodies incorporate the light elements expected to be inside Earth's high-pressure core?
D. Did Psyche form under more oxidizing or more reducing conditions than Earth's core?
E. What is the unique topography of this metal world?

Initial feasibility also includes a cost perspective. ***Is the concept financially viable?*** The Announcement of Opportunity (AO NNH14ZDA014O) specified a cost cap of $450M in fiscal year 2015 dollars for phases A-D, not including the launch vehicle. At early stages of mission concept formulation there is not enough detailed information to perform parametric cost estimates. Therefore, an analogy-based approach was adopted to assess initial cost feasibility. There was a strong resemblance to the Discovery-class Dawn mission as an analogous mission. Assuming that the science could be attained with a heritage suite of instruments, and the overall mission structure was similar to Dawn, the Psyche concept appeared to be affordable and fit within the resources of Discovery-class missions.

2. TRADE SPACE EXPLORATION

Science implementation is evaluated on the merit of the instruments and mission design for addressing the science goals and objectives.

Mission design analysis is a critical component in formulating planetary mission concepts. Prior to the A-Team study, mission design analysis was performed including various propulsion and launch vehicle options. Both chemical and solar electric propulsion (SEP) options were considered for post-launch transportation. Four different "architecture seeds" were identified, ranging from what is expected to be the minimum cost mission to orbit Psyche only, to what is probably a maximum cost mission of orbiting both Psyche and Hebe, and then flying by Eunomia.

After much discussion by the science team it was decided that the science obtained from orbiting Psyche only was sufficient for a Discovery-class mission. Orbiting another main-belt asteroid, such as Hebe, could be interpreted as detracting from the science narrative, which was intended to make the case that Psyche is a mission to answer key science questions about the formation of terrestrial planets, and is not primarily an asteroid mission. Therefore, it was concluded that going to a second main-belt asteroid could send the wrong message, making the mission look like a multiple main belt asteroid mission similar to Dawn.

A-Team facilitated a second study focused on the Psyche payload/instrument options. The study began with a review of the science traceability, i.e., the observables and measurement objectives outlined in the previous study (Fig. 2). A critical component of this study was to identify the threshold mission. ***What is the minimum asteroid mission that may be scientifically sufficient for Discovery?***

Potential instrument partnerships and contributors were identified. In collaboration with the Psyche team, A-Team provided the assessment value framework that informed and assisted the Psyche science team's ultimate payload suite decisions. Assessment factors were two-fold, and included both the technical ability of the instrument to achieve the science objectives and the associated cost to develop, build, and V&V the instruments. Instrument cost data were based on the NASA Instrument Cost Model database, which is a parametric cost model of flown instruments.

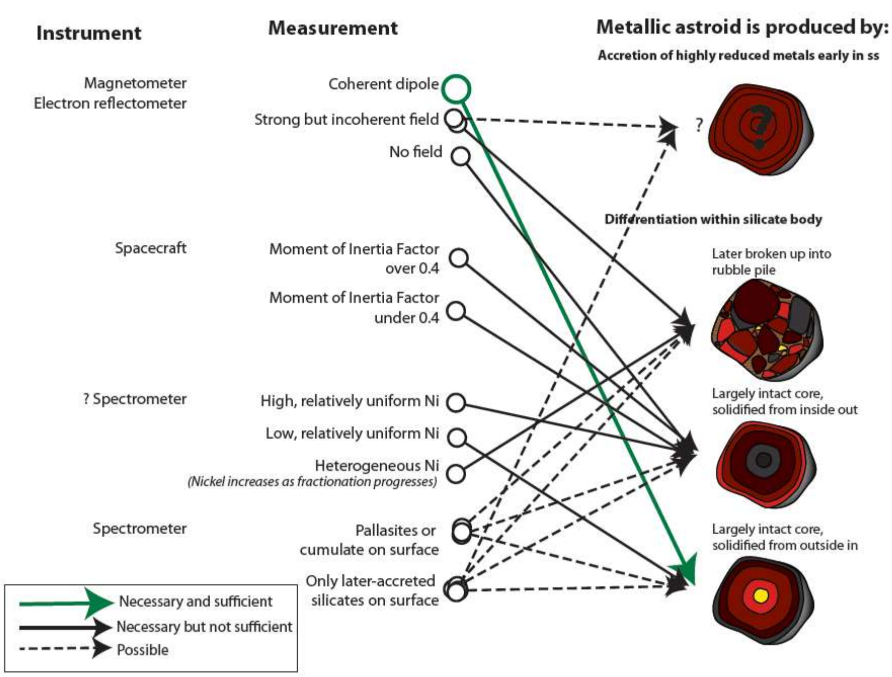

Figure 2. This schematic path from measurements to hypothesis testing helped to guide science traceability discussions. It demonstrates some of the paths and potential science objectives about formation of terrestrial planets.

3. SPACECRAFT POINT DESIGN AND COST ESTIMATE

After the architectural-level trade space decisions were completed, the Psyche team began their initial baseline concept development, defining the major subsystem elements with acceptable margins and reserves. They issued a Request for Information (RFI) to commercial vendors, including some non-traditional NASA industry providers. Space Systems Loral (SSL) emerged as a promising partnership with their commercial expertise in SEP subsystems.

Team X conducted a concurrent engineering study for a hybrid spacecraft design, jointly built by Space Systems Loral and the Jet Propulsion Laboratory. At the time of the Team X study the SSL/JPL interfaces were not well defined, which resulted in interface challenges during the Team X study in the areas of propulsion, avionics, thermal, mechanical, and power subsystems. Ultimately, these interfaces were resolved and SSL would provide the SEP chassis and JPL would provide the avionics.

While Team X has collaborated with many commercial vendors over the years, this study was unique in that SSL had a nearly one-to-one ratio of technical subsystem subject matter experts (SMEs) to match the Team X SMEs. This study was challenging because in some cases, the Team X design subsystem models did not encompass the industry partner's technical capabilities. In real-time the Team X SMEs adjusted their models and/or provided data "over-rides" to incorporate the industry partner's technical design information (Fig. 3).

JPL's Institutional Cost Models (ICMs), embedded within Team X, were used to estimate the overall lifecycle mission cost. The ICMs are quasi-grassroots estimates that represent the "doing" organizations best estimate to perform the task statement for the Work Breakdown Structure (WBS), based on the scope of work and the cost/risk profile.

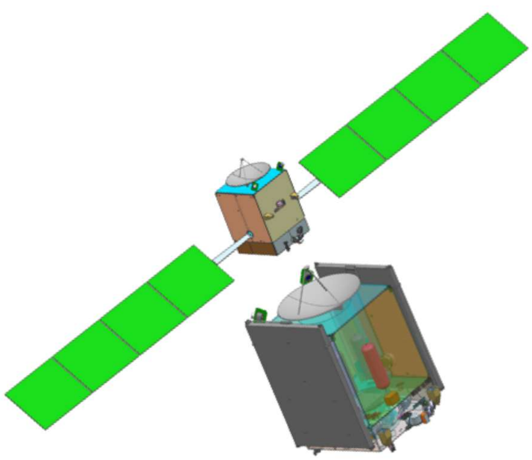

Figure 3. Hybrid point design for a joint SSL/ JPL built spacecraft as conceived in Team X.

4. SCIENCE, TEHCNICAL, MANAGEMENT, AND COST REVIEW

Technical reviews are typically time consuming and inefficient given the ratio of the small number of critical findings identified to the large number of Review Item Discrepancy (RID) items. Team X routinely performs mission and instrument concept reviews using concurrent and collaborative engineering techniques and subject matter experts. This method has been demonstrated to improve both the efficiency and effectiveness of scientific, technical, management and cost (STMC) internal JPL reviews for major spaceflight mission and instrument proposals [5].

Team X modelled their STMC review process from the NASA review process, instantiating both science and technical review panels. Scientists assess the science merit and science implementation evaluation criteria. Engineers, including cost engineers, and a project manager assess the mission implementation and Cost/Risk evaluation criteria. Both the Psyche Step I and Step II proposals were evaluated using this process.

5. STRATEGY AND COMMUNICATION DEVELOPMENT

NASA's Discovery Program is a competed opportunity that involves a two-step proposal process. Twenty-seven proposals were submitted to NASA during Step-I. After a thorough review process, NASA down-selected to five mission concepts for further consideration. The proposal strategy employed during Step-I differs from the proposal strategy approach required in Step-II. First, in Step-I the competition of the other concepts is unknown; however, in Step-II the mission concepts are announced in a press release. Therefore, the communication strategy, e.g., win themes and death threats, needs to be tailored based on the other competing mission concepts. The JPL Innovation Foundry and the Solar System Formulation Program Office provided experienced coaching to the Psyche team in the development of their Step-II proposal to communicate their concept successfully.

6. NASA SELECTS DISCOVERY MISSION

On January 4, 2017 NASA issued the following press release, "The Psyche mission will explore one of the most intriguing targets in the main asteroid belt – a giant metal asteroid, known as 16 Psyche, about three times farther away from the sun than is the Earth. This asteroid measures about 130 miles (210 kilometres) in diameter and, unlike most other asteroids that are rocky or icy bodies, is thought to be comprised mostly of metallic iron and nickel, similar to Earth's core. Scientists wonder whether Psyche could be an exposed core of an early planet that could have been as large as Mars, but which lost its rocky outer layers due to a number of violent collisions billions of years ago. The mission will help scientists understand how planets and other bodies separated into their layers – including cores, mantles and crusts – early in their histories."

7. CONCLUSION

Psyche's successful formulation approach focused on: 1) ***Initial Feasibility*** from both science and cost perspectives; 2) ***Trade Space Exploration*** by identifying options across system architectures, then analysing high-level trades among the end-to-end system elements, i.e., mission design; launch vehicles, payload/instruments, and spacecraft/platforms; 3) ***Point Design and Cost Estimate*** developed jointly by JPL and SSL industry partner defining subsystem interfaces; 4) ***Science, Technical, Management, and Cost Reviews*** for both Step I and Step II proposals; and 5) ***Strategy and Communication Development*** to mitigate Step-1 major and minor weaknesses, and highlight strengths.

Key decisions were made about partnerships to form, and options to cull. This structured method to expand the trade space, followed by a systematic assessment to contract the options (Fig. 4) was critical to identify the concept design that delivered the best science per value for the Discovery Psyche mission concept [1].

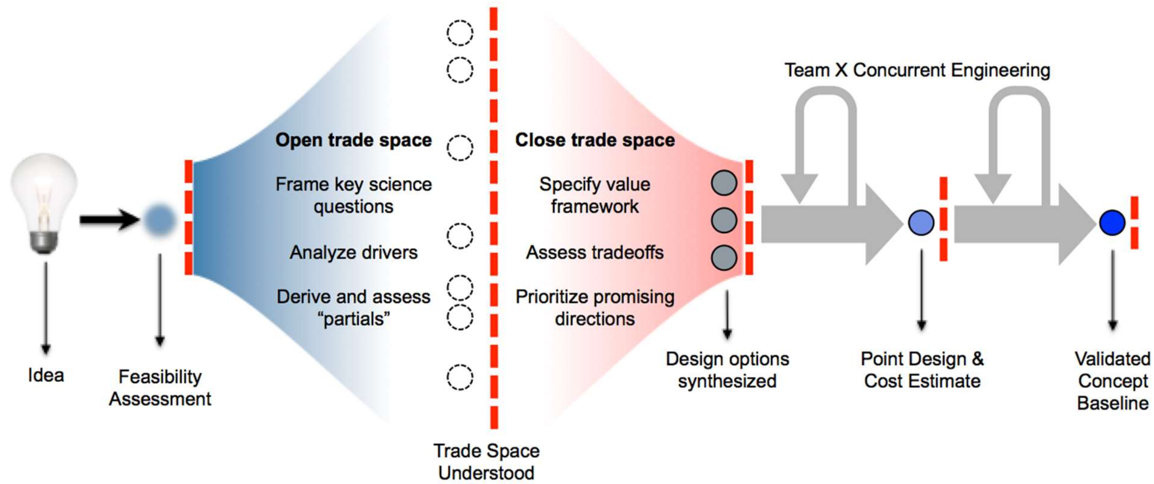

Figure 4. Systematic evolution of an idea yields a robust concept that can be advocated successfully, and provides an organizing structure for the formulation lifecycle. [1]

8. ACKNOWLEDGMENTS

While one person might have an idea, it takes a team of people to turn that idea into a realizable mission concept. The authors would like to thank the following people that contributed to the Psyche mission concept: Brent Sherwood and Kim Reh from the Solar System Formulation Program Office; John Brophy as the initial Concept Champion; Damon Landau as the A-Team Mission Design Specialist, responsible for the initial mission design analysis; A-Team members of studies #1317 and #1368; Team X members of studies #1460, #1482, #1546, #1704, and #1723; Karen Lum, Step 1 Proposal Manager; Rolf Danner, Step 2 Proposal Manager; and finally, the Psyche concept development and proposal team members.

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

9. REFERENCES

1. Sherwood, B., McCleese, D., (2013). JPL Innovation Foundry, *Acta Astronautica*, **89** 236-247.

2. Oh, D.H, Collins, S., Goebel, D., Hart, W., Lantoine, G., Snyder, S., Whiffen, G., (2017). Development of the Psyche Mission for NASA's Discovery Program, *35th Annual International Electric Propulsion Conference*, Georgia Institute of Technology, Atlanta, GA, IEPC-2017-153, 1–19.

3. Elkins-Tanton, L.T., Asphaug, E., Bell, J., Bercovici, D., Bills, B.G, Binzel, R.P., Bottke, W.F., Jun, I., Marchi, S., Oh, D., Polanskey, C.A., Weiss, B.P., Wenkert, D., Zuber, M.T., (2014). Journey to a Metal World: Concept for a Discovery Mission to Psyche, *45th Lunar and Planetary Science Conference*, Paper 1253.

4. Committee on the Planetary Science Decadal Survey, Space Studies Board, Division on Engineering and Physical Sciences (2011). *Vision and Voyages for Planetary Science in the Decade 2013-2022*, National Academies Press, Washington D.C., 398 pp.

5. Nash, A., (2016). Recent Improvements in Concurrent Engineering Reviews, *7th International Systems & Concurrent Engineering for Space Applications Conference (SECESA 2016),* Madrid, Spain.